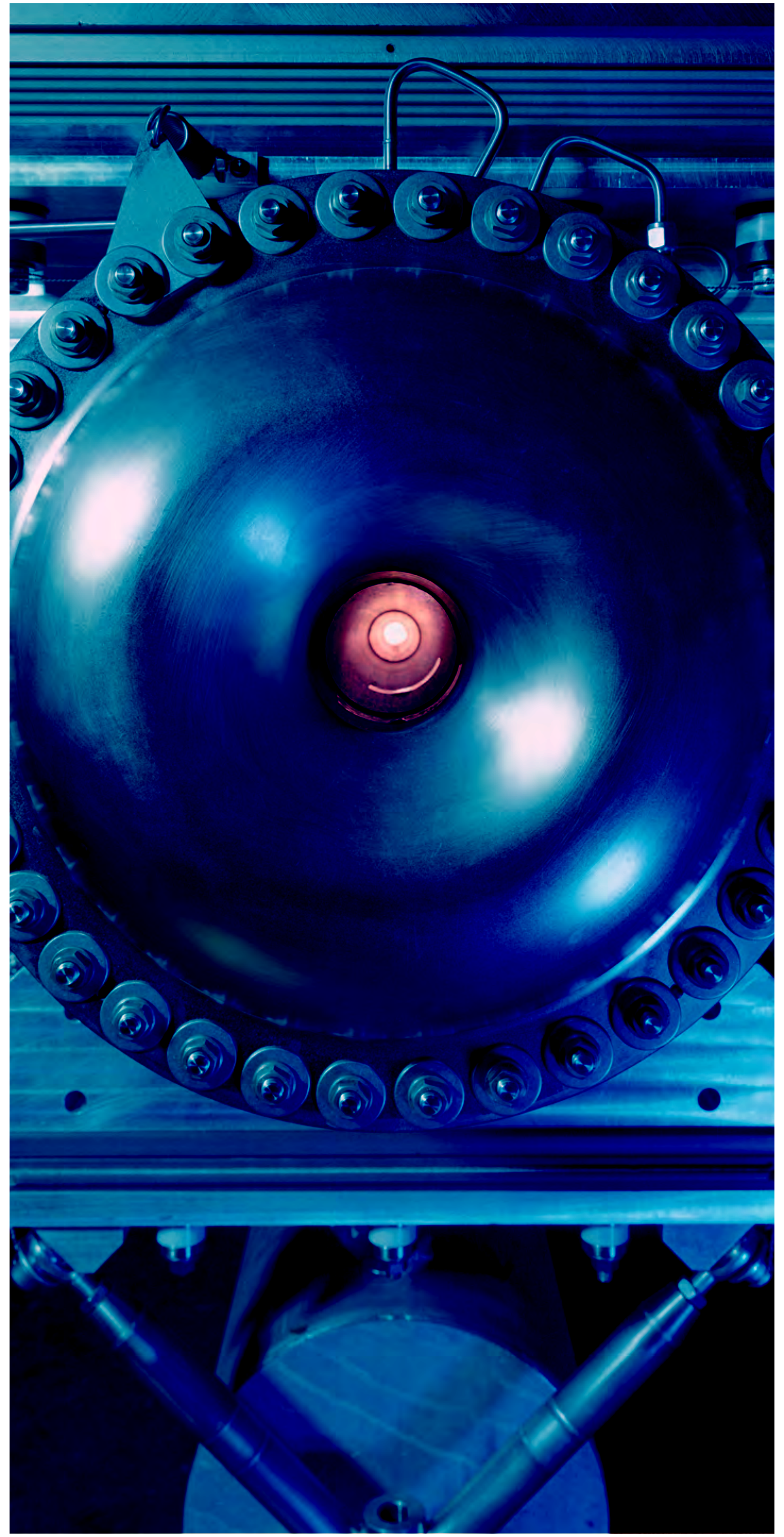
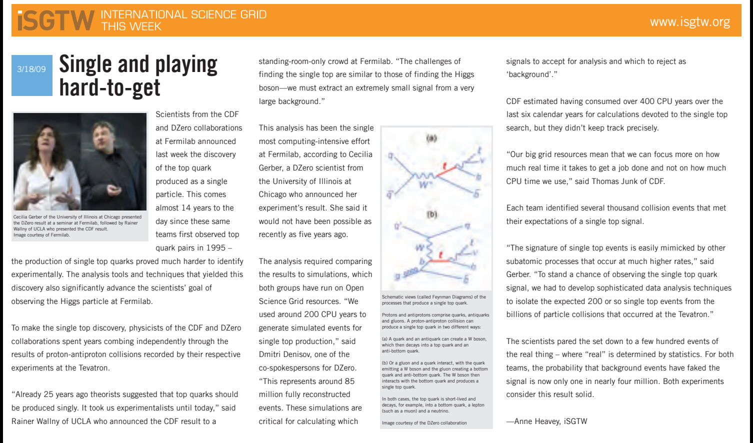


ANALYSIS

PROCESSING MASSIVE DATASETS

Current Fermilab collider detectors record data at a rate of 20 megabytes per second, continuously for about nine months every year. This represents roughly 100 particle collisions per second, each 200 kilobytes in size, that the triggering system accepts and records for further study. Experiments at CERN's Large Hadron Collider will record ten times as much data.

Physicists at Fermilab and at the collaborating institutions use complex software with hundreds of thousands of lines of code to reassemble the data into a form the human mind can grasp and analyze.



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3/18/09

Single and playing hard-to-get

Cecilia Gerber of the University of Illinois at Chicago presented the DZero result at a seminar at Fermilab, followed by Rainer Wallny of UCLA who presented the CDF result.
Image courtesy of Fermilab.

Scientists from the CDF and DZero collaborations at Fermilab announced last week the discovery of the top quark produced as a single particle. This comes almost 14 years to the day since these same teams first observed top quark pairs in 1995 – the production of single top quarks proved much harder to identify experimentally. The analysis tools and techniques that yielded this discovery also significantly advance the scientists' goal of observing the Higgs particle at Fermilab.

To make the single top discovery, physicists of the CDF and DZero collaborations spent years combing independently through the results of proton-antiproton collisions recorded by their respective experiments at the Tevatron.

"Already 25 years ago theorists suggested that top quarks should be produced singly. It took us experimentalists until today," said Rainer Wallny of UCLA who announced the CDF result to a standing-room-only crowd at Fermilab. "The challenges of finding the single top are similar to those of finding the Higgs boson—we must extract an extremely small signal from a very large background."

This analysis has been the single most computing-intensive effort at Fermilab, according to Cecilia Gerber, a DZero scientist from the University of Illinois at Chicago who announced her experiment's result. She said it would not have been possible as recently as five years ago.

The analysis required comparing the results to simulations, which both groups have run on Open Science Grid resources. "We used around 200 CPU years to generate simulated events for single top production," said Dmitri Denisov, one of the co-spokespersons for DZero. "This represents around 85 million fully reconstructed events. These simulations are critical for calculating which signals to accept for analysis and which to reject as 'background'."

Schematic views (called Feynman Diagrams) of the processes that produce a single top quark.

Protons and antiprotons comprise quarks, antiquarks and gluons. A proton-antiproton collision can produce a single top quark in two different ways:

(a) A quark and an antiquark can create a W boson, which then decays into a top quark and an anti-bottom quark.

(b) Or a gluon and a quark interact, with the quark emitting a W boson and the gluon creating a bottom quark and anti-bottom quark. The W boson then interacts with the bottom quark and produces a single top quark.

In both cases, the top quark is short-lived and decays, for example, into a bottom quark, a lepton (such as a muon) and a neutrino.

Image courtesy of the DZero collaboration

CDF estimated having consumed over 400 CPU years over the last six calendar years for calculations devoted to the single top search, but they didn't keep track precisely.

"Our big grid resources mean that we can focus more on how much real time it takes to get a job done and not on how much CPU time we use," said Thomas Junk of CDF.

Each team identified several thousand collision events that met their expectations of a single top signal.

"The signature of single top events is easily mimicked by other subatomic processes that occur at much higher rates," said Gerber. "To stand a chance of observing the single top quark signal, we had to develop sophisticated data analysis techniques to isolate the expected 200 or so single top events from the billions of particle collisions that occurred at the Tevatron."

The scientists pared the set down to a few hundred events of the real thing – where "real" is determined by statistics. For both teams, the probability that background events have faked the signal is now only one in nearly four million. Both experiments consider this result solid.

—Anne Heavey, iSGTW

Typically, a Tevatron detector dataset holds hundreds of millions of particle collision events. Sophisticated programs on large parallel computing farms reconstruct particle tracks and other objects in each dataset, cull the dataset down to hundreds of thousands of events, and select a strategic subset of each event's total information to compare with simulations and search for new and interesting physical phenomena.

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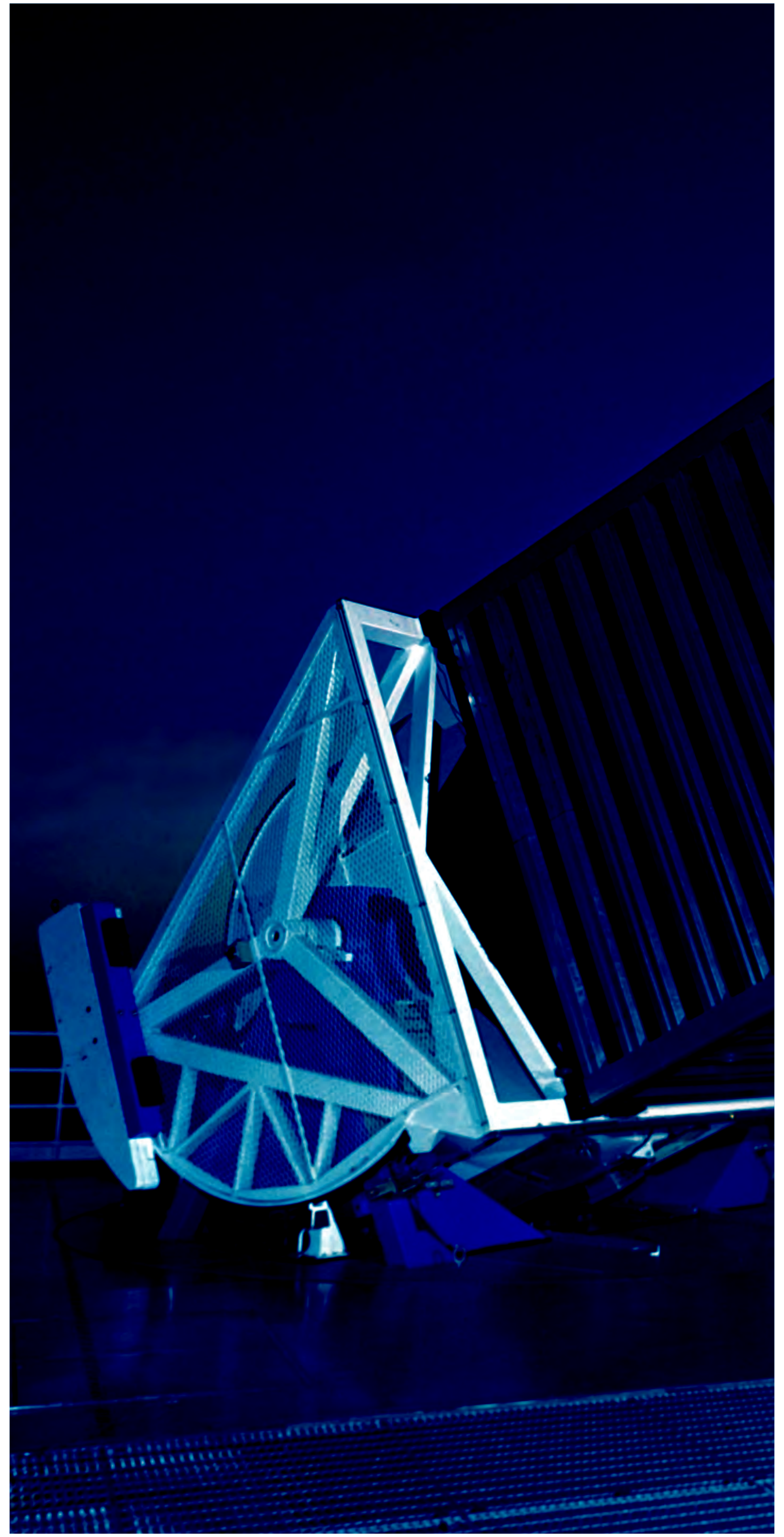
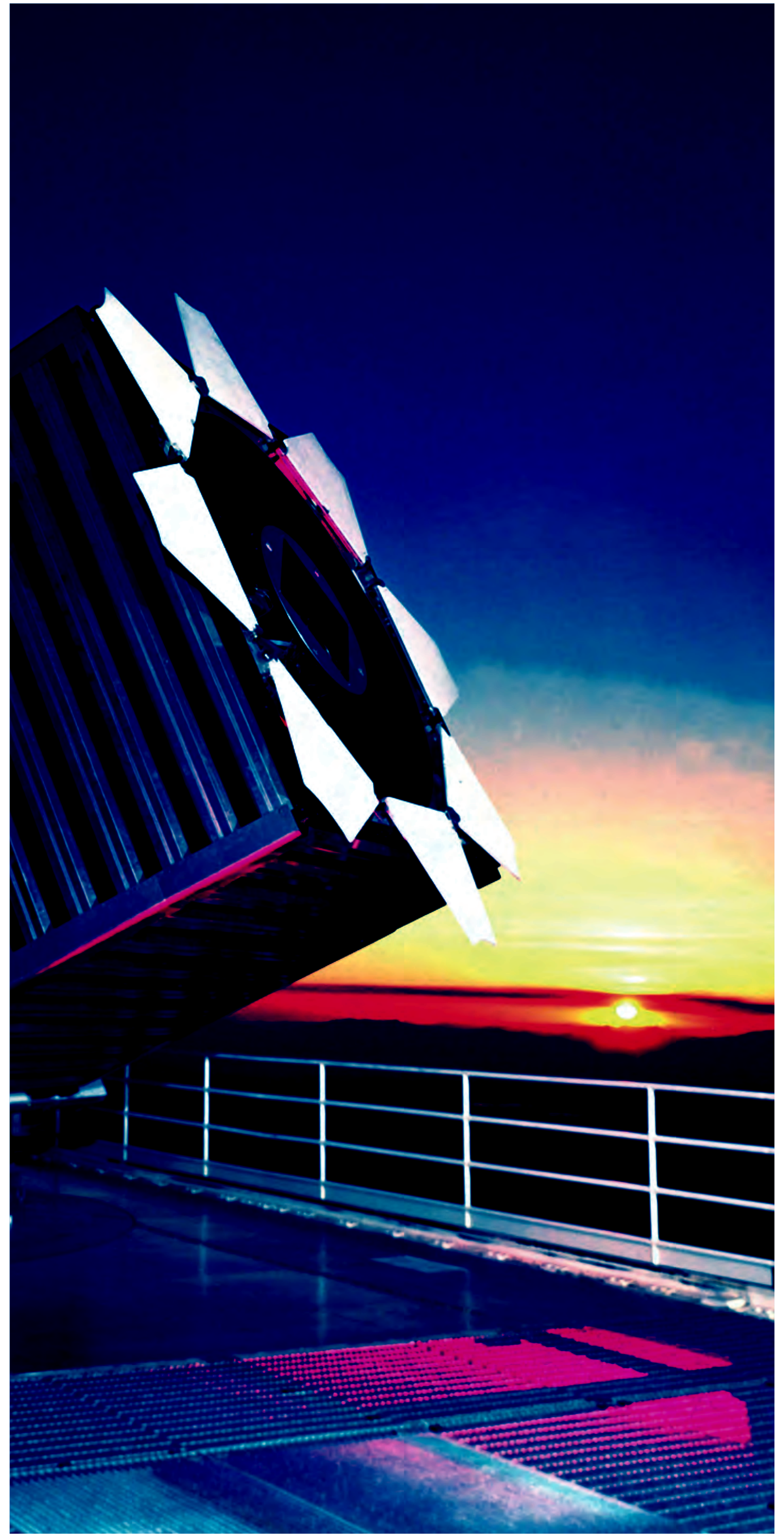


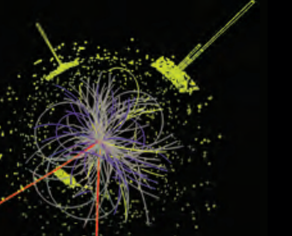


SIMULATION

MODELING PARTICLE ACCELERATORS AND DETECTORS AND ADVANCING PARTICLE PHYSICS THEORY

ACCELERATOR SIMULATIONS

Fermilab accelerator scientists run modeling codes on parallel clusters of up to 20,000 processors at Fermilab and other national labs. Through the DOE/SciDAC COMPASS project, Fermilab developed Synergia, a parallel 3D accelerator modeling code for multi-particle effects. The scientists have used it to improve the performance of their colliding beam accelerator, the Tevatron, and are already studying potential upgrades for the Large Hadron Collider at the European laboratory, CERN.



DETECTOR SIMULATIONS

Physicists at Fermilab develop computer simulations of particle collisions expected to occur in their detectors and run them millions of times. In this way they gather enough statistics to confidently identify signals in the real data that they can map to particular particles and phenomena. The bulk of these simulations run on Open Science Grid resources.

THEORETICAL PHYSICS SIMULATIONS

The theory of quantum chromodynamics (QCD) describes how quarks and gluons bind together to form other particles, such as protons and neutrons, and in turn, atomic nuclei. Uncovering the most important predictions of QCD from the comprehensive Standard Model theory of particle physics requires large-scale numerical simulations.

Fermilab participates in the U.S. QCD computational infrastructure project and in DOE/SciDAC-2 for lattice QCD. The laboratory operates four high-performance clusters with an aggregate sustained performance of 12 TeraFLOPS for lattice QCD simulations, with peak performance about five times higher.

SIMULATIONS OF TELESCOPE SIGNALS FOR THE DARK ENERGY SURVEY, EACH OF WHICH CAN PRODUCE OVER 3 TERABYTES OF DATA, WILL ENABLE ASTROPHYSICISTS TO DECIPHER REAL IMAGES OF MORE THAN 300 MILLION GALAXIES.